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Using verified citizen science as a tool for monitoring the European hornet (*Vespa crabro*) in the island of Sardinia (Italy)

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Abstract

The European hornet, *Vespa crabro* L. (Hymenoptera: Vespidae), is a eusocial insect native to Eurasia that was accidentally introduced in the island of Sardinia (Italy) in 2010. This alien generalist predator could impact on native insect species through predation or competition by modifying interspecific relations in sensitive island ecosystems. As part of the Interreg project ALIEM, the present work regarded the first monitoring activity of the European hornet conducted in Sardinia by means of verified citizen science. The main goals of this study were to define the distribution area of the wasp in 2018 and evaluate the profile and the performance of citizen scientists. Our results showed that *V. crabro* is mainly located in north-eastern Sardinia and that the hotspot was probably the commercial port of Olbia. Furthermore, data provided by contributors were very accurate and none of the parameters considered to define the participants (age, gender, education level, job category) was a true predictor of a volunteer's ability to recognise the wasp. In conclusion, this small-scale study suggests that citizen scientists could be a valuable aid to monitor already-established alien species and could be part of a surveillance network for early detection of other potentially invasive alien species not yet introduced in Sardinia, such as the yellow-legged hornet, *Vespa velutina*, which is already present in northern Italy.

Keywords

Alien species; biological invasion; data quality; European hornet; public information.

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Introduction

The European hornet, *Vespa crabro* L. (Hymenoptera: Vespidae), is a social insect native to Eurasia (Carpenter and Kojima 1997), being distributed from Japan to the Iberian peninsula. Due to its predation ability, *V. crabro* was voluntarily introduced and successfully established in North America in the mid-nineteenth century as a predator of forest-damaging caterpillars (Shaw and Weidhaas 1956). This species was accidentally introduced to Central America in 2010, even though it does not seem to have established (Landolt et al. 2010). The European hornet constructs large paper nests mainly in hollow trees, but it is also able to colonise abandoned beehives, hollow walls and other building cavities (Matsuura and Yamane 1990). Several subspecies of the European hornet are distributed around the world. Amongst these, *V. crabro crabro* is widely spread in Italy (Carpenter and Kojima 1997; Dubatolov et al. 2003; Fernández 2004).

In Sardinia, the second largest island in the Mediterranean basin, the presence of *V. crabro* was first reported by Costa (1883), but specimens were not kept in any entomological collection and this report was not confirmed in the following years. In fact, no specimens of *V. crabro* from Sardinia were reported in the studies of Guiglia (1948, 1972) on Italian and European wasps. Subsequently, its absence in the island was noted in the checklist of the Italian fauna (Stoch 2003). Conversely, this species is present in other Mediterranean islands, such as Corsica and Sicily. The presence of *V. crabro* in Sardinia was ascertained only in August 2010, based on several findings of this species in Cannigione (municipality of Arzachena) (41°05'07"N, 9°25'52"E). The collected specimens were identified and stored in the entomological collections of the University of Sassari and University of Cagliari (Italy).

Surveillance and monitoring of alien species over large areas require a large amount of funding and personnel. Unfortunately, these resources are often scarce, thus resulting in a lack of information about current and potential invasions (Delaney et al. 2008; Crall et al. 2010). As a consequence, invasive species continue to spread throughout the world, resulting in economic and environmental damage (Mack et al. 2000; Pimentel et al. 2005; Stohlgren and Schnase 2006; Beggs et al. 2011; Lester and Beggs 2019).

Monitoring by "citizen scientists" can be an alternative means to solve this problem, because it requires fewer resources (Lodge et al. 2006). Although volunteer-based monitoring reduces research costs, the decrease in the accuracy of data collected by citizen scientists in comparison to those collected by few experts must be carefully considered (Ericsson and Wallin 1999; Genet and Sargent 2003). Nevertheless, the great sampling power derived by a high number of volunteers could offset the greater variability in collected data (Schmeller et al. 2009). Two types of citizen science methods have been recently proposed as follows: "*direct*", without data verification and "*verified*", in which all observations collected by citizen scientists are verified by "true researchers" (Gardiner et al. 2012). Previous studies showed that citizen scientists could identify large organisms very well (Bloniarz and Ryan 1996), whereas they often misidentified inconspicuous species (Mumby et al. 1995; Brandon et al. 2003; Genet and Sargent 2003). In general, insects are difficult to identify because of their small size

and great variation in morphological features, even within the same taxonomic group. Few studies have assessed the accuracy of the identification of insects made by citizen scientists (Gardiner et al. 2012; Ratnieks et al. 2016; Roy et al. 2016). Previous citizen science studies evaluated different parameters such as age, education, experience, science literacy and attitudes (Crall et al. 2011), as well as size of the species monitored (Delaney et al. 2008), as predictors of volunteer's ability to collect data. However, no studies have considered whether there are predictors of voluntary participation that could be used to facilitate the recruitment of citizens in citizen science programmes.

In this study, as a part of the Interreg ALIEM project "Action pour Limiter les risques de diffusion des espèces Introduites Envahissantes en Méditerranée" (http://interreg-maritime.eu/web/aliem), the monitoring of the European hornet was undertaken for the first time in Sardinia (Italy) in 2018. The project involves institutional partners from five border territories of France and Italy and aims to develop adequate tools for early detection of invasive pests and a cross-border observatory for flora and fauna. Considering that *V. crabro* is a large insect that can be easily noticed and that other similar hornet species are not present in Sardinia, we monitored its distribution in the island by using *verified* citizen science, as already done for other insect species in other regions of Italy (Mason et al. 2015). Our main goal was to determine the area of spread of the European hornet in Sardinia after its introduction in 2010. Furthermore, in order to better define the specific profile of the citizen scientist, we analysed the features of citizens (age, gender, education level and job) who joined our monitoring programme. Finally, this study assessed the general accuracy of the data collected by volunteers in relation to the features considered.

Materials and methods

Volunteer recruitment

The promotion of the monitoring and reporting activities was performed in 2017 with a publicity campaign conducted throughout Sardinia. The participants were recruited through the following channels: 1) advertisements posted online; 2) leaflets distributed in public meeting places (e.g. bars); 3) public seminars and meetings; 4) articles published in local newspapers and 5) informative documents sent via email to municipalities, research centres, environmental organisations and institutions located in Sardinia. Citizens were asked to report *V. crabro* nests and/or adults and were invited to place a home-made funnel-type trap in their own property (e.g. farm) to monitor *V. crabro* adults. The trap contained 33 centilitres of beer as bait and had to be checked by citizens every two weeks.

The protocol guidelines for citizens were disseminated online and on paper and consisted of the following activities: 1) supply of information about the project to raise public awareness of the importance of monitoring and to encourage participation in the programme; and 2) release of a guide and a form to be filled in with personal infor-

mation and European hornet report data to recruited participants. The identification guide outlined the main morphological characteristics of *V. crabro* compared to those of the German yellow jacket, *Vespula germanica*, the most common wasp in Sardinian environments and the yellow-legged hornet, *Vespa velutina*, not reported in the island so far, but already present in some Italian regions (Liguria and Piedmont). The latter species was included in the guide in order to create a prevention surveillance network because of its negative impact in the areas of new introduction (Choi et al. 2012).

Hornet data collection

All volunteers were asked to report nests or individuals of the European hornet found in 2018, by including information about *date*, *place* (geographic coordinates) and *habitat type* (urban or rural). Participants were also encouraged to provide other information, such as *environmental sub-category* (e.g. forest, agricultural, apiary, inside a building and garden) and *hornet behaviour* (e.g. in flight, predating bees or other preys and eating fruit). In order to verify the accuracy of the report, citizens were required to provide photos, videos or hornet samples as evidence. Alternatively, the citizen report was validated through site inspection by researchers.

Participant evaluation

Personal details of participants (i.e. age, gender, education level and job) were classified as follows: age *below* or *above* the median age of participants; *male* or *female*; *middle school*, *high school* or *university* education level; and, finally, *outdoor*, *office* or *institutional* job. The different job types were selected according to their likelihood of finding and/or reporting the presence of the European hornet. In particular, outdoor workers are likely to come into contact with local flora and/or fauna and thus detect and report the disturbance or damage caused by the European hornet. Office workers are less likely to be in contact with nature and recognise the presence of the hornet. Finally, institutional employees, who work for the government and might work indoors and/or outdoors (mixed category), have the common characteristic of being likely to report the presence of *V. crabro* due to a sense of duty towards citizens. In order to measure the accuracy of the data collected by volunteers, all reports were verified by researchers and analysed as a whole and within the categories chosen in this study. Citizens were also asked to specify the channel through which they became aware of the monitoring programme.

Statistical analyses

Differences in the frequency of correct and incorrect reports (i.e. data accuracy) were analysed separately for each predictor (age, gender, education level and job) using chi-

squared tests (two-way tests). A chi-squared test was also used to measure the proportional difference in identification accuracy between nests and single-individual reports. To reduce the chances of a type I error, continuity correction was used for the chi-squared test because the sample size was less than 200 (Sokal and Rohlf 1981). A binomial exact test was used to test for differences in the frequency of reports from urban and rural areas. All statistical analyses were conducted using R software (R Core Team 2018).

Results

From May to November 2018, the European hornet was reported 125 times, out of which 41 (32.8%) referred to nests and 84 (67.2%) to single adults. The number of correct reports was 101 (80.8%). *Vespa crabro* was found in a large area of north-eastern Sardinia covering approximately 6000 km^2 and corresponding to 20% of the total regional area. Correct records were collected between 40°21'44"N, 8°48'50"E (Fig. 1). All the incorrect reports (n = 24) were recorded outside this area. Most reports were concentrated in the surroundings of the commercial port of Olbia (Fig. 2). The total number of reports received from rural areas (n = 67) was significantly higher than that of urban areas (n = 34) (Binomial test, $P < 0.01$).

The accuracy of recognition was greater for hornet's nests than individuals (95.1% vs. 73.8%, respectively) (χ = 6.75, df = 1, P = 0.009). The most common error made by citizen scientists was the misidentification of *V. crabro* with other species belonging to the genera *Scolia* and *Eumenus*. The report accuracy was not affected by the four selected predictors considered (age: χ = 0.322, df = 1, P = 0.569, Fig. 2A; gender: χ = 0.007, df = 1, P = 0.930, Fig. 2B; education level: χ = 0.667, df = 2, P = 0.716, Fig. 2C; job category: χ = 1.616, df = 2, P = 0.445, Fig. 2D).

The average profile of the citizen scientists who voluntarily participated in the monitoring programme can be summarised as follows: male (68% of reports), mean age 46.5 ± 0.9 years old, with an outdoor work (55% of cases) and high-school level of education (46%).

The most effective channel for spreading the information about the monitoring programme amongst citizens was *word of mouth* (from us or amongst citizens), with 56% of reports, followed by *online notices* (42.4% of cases) and, finally, *newspaper advertising*, with only 1.6% of reports.

Discussion

Based on the monitoring activity of *V. crabro* carried out in Sardinia during 2018 by a citizen science programme, the distribution of the European hornet is restricted to the north-east of the island. In addition, considering the location of the majority of reports, the hotspot for introduction of this wasp is likely associated with the Olbia sea-

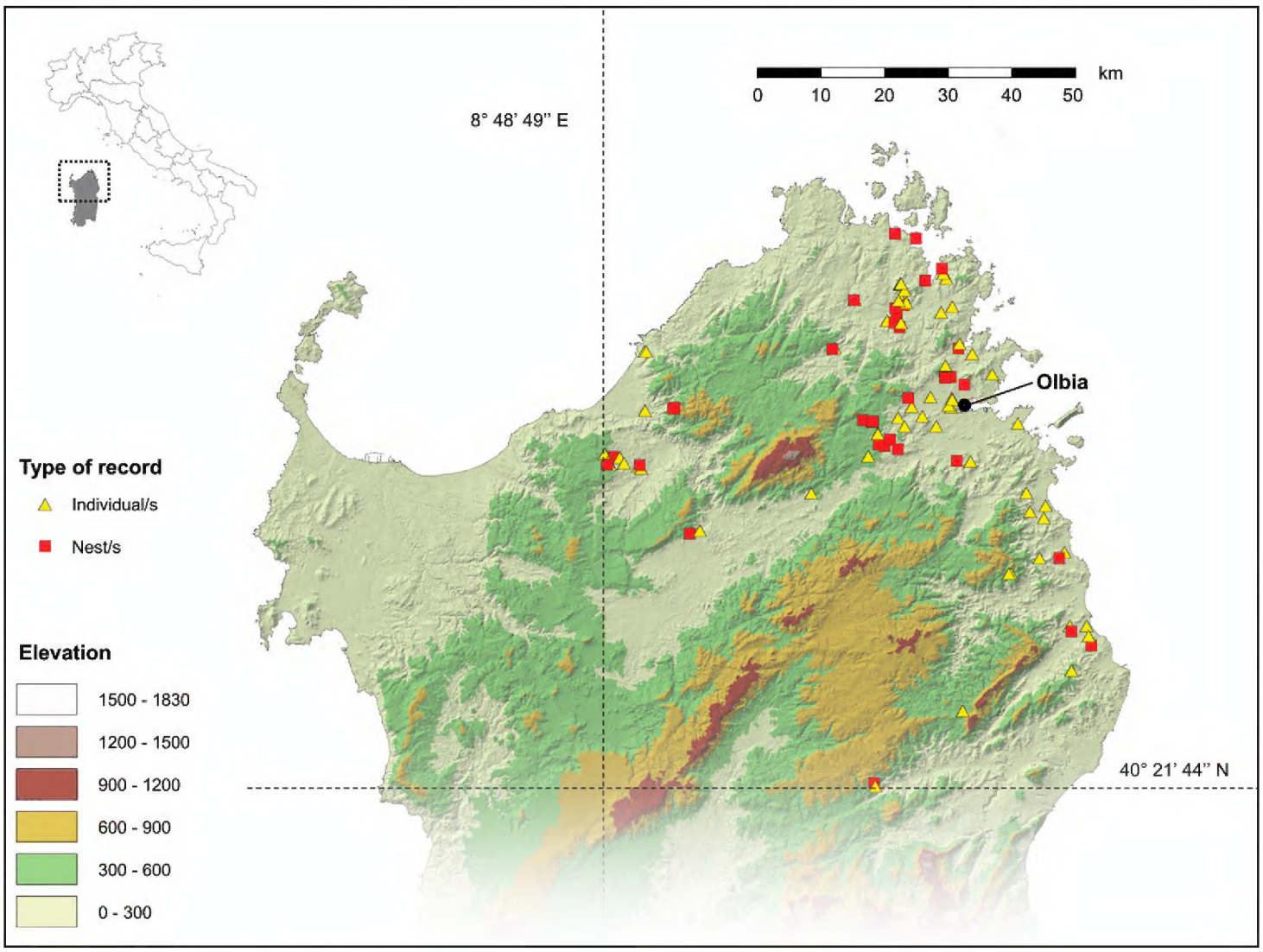

Figure 1. Distribution of the *Vespa crabro* in Sardinia (Italy).

port, which represents a point of continuous commercial traffic (e.g. timber transport) between Sardinia and the Italian peninsula and other European and extra-European countries. In fact, the introduction of potentially invasive species in new areas takes place mainly through human and goods traffic (Spradbery and Maywald 1992; Hulme 2009; Beggs et al. 2011; Lester and Beggs 2019). For example, fecundated queens could have been easily introduced through timber import (Beggs et al. 2011; Lester and Beggs 2019).

The present hornet distribution in Sardinia and the fact that *V. crabro* had not been confirmed before 2010 suggest that the report of Costa (1883) was probably incorrect. An alternative, but less probable, hypothesis could involve the extinction of the species in the island and its subsequent re-introduction. Future genetic studies could shed light on the introduction pattern of *V. crabro* in Sardinia.

In order to establish in a new region, the introduced queens have to find a nest, adapt to the new environment (e.g. climate), find food, resist new pathogens, escape predators and overcome native competitors (Lester and Beggs 2019). The high fertility of a single queen is one of the main characteristics that make social Vespidae a highly successful invasive species and difficult to eradicate all over the world (Beggs et al. 2011). Therefore, nest foundation is clearly a key moment in the adaptation process, which acts by selecting the most suitable characteristics to promote invader dispersal.

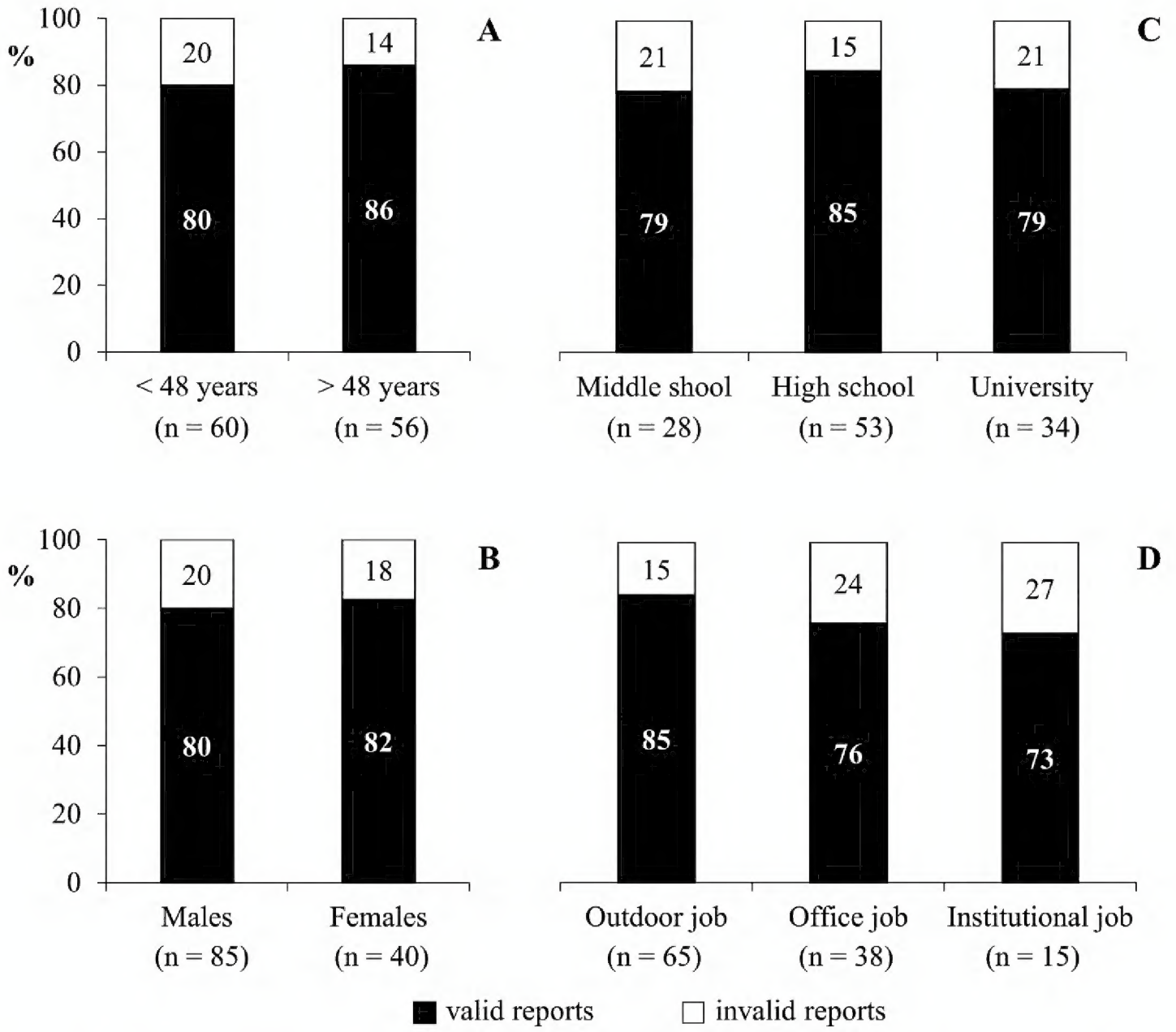

Figure 2. Percentage incidence of valid and invalid reports in: **A** citizens below and above the median age of participants (48 years) **B** male and female volunteers **C** participants with a middle school, high school and university education level **D** participants with an outdoor, office and institutional job. No significant differences were observed for any of the comparisons made.

The response of a species to a new environment can vary greatly and a non-harmful species in its native region can exhibit invasive behaviour in areas of new introduction (Monceau et al. 2015a). In fact, the introduction of alien generalist predators may impact the food web, by modifying the interspecific relationships through predation and/or competition (Snyder and Evans 2006; Bourdeau et al. 2011). This is the case for *V. germanica*, which is a harmless species to honeybees in its native region (Pusceddu et al. 2018), but becomes a threat in areas where it is introduced (Lester and Beggs 2019). Despite having a preference for bees as food source (Cini et al. 2018), *V. crabro* is known as a mild predator of *Apis mellifera* in Europe (Morse and Nowogrodzki 1990), being subjected to protection measures in Germany since 1987 (Monceau et al. 2015b). This probably depends on the long process of arms-race co-evolution that involves prey and predator (Baracchi et al. 2010; Pusceddu et al. 2017). However, specific studies on impacts of the European hornet as alien species are missing. In addi-

tion, the congeneric species *V. velutina* and *V. orientalis*, which share a similar seasonal phenology (Monceau et al. 2015b) and food preferences (Cini et al. 2018) with *V. crabro*, have not yet been reported in Sardinia.

The lack of native competitors, the favourable climate and the availability of nesting sites (e.g. ancient olive groves) could facilitate the spread of *V. crabro* throughout the island. This paper provides basic information on the spread of *V. crabro* in an introduced area, but further studies are needed to understand its expansion speed and its economic and ecological impact on sensitive insular ecosystems.

The highest number of reports of *V. crabro* in September and October (28 and 26, respectively) is in line with the seasonal biology of this species (Matsuura and Yamane 1991). In fact, nest foundation by a mated queen occurs in spring, with the colony growing from summer until the end of autumn, when new queens emerge, mate and overwinter, while males and the colony die (Matsuura and Yamane 1991). As a result, citizens become more aware of the presence of hornets when colonies are in full expansion. In addition, the potential impact of the European hornet on human activities partly explains the high interest of volunteers.

A higher number of reports was received from rural areas as compared with that received from urban areas. This is an interesting result considering that citizens' reports tend to arrive most frequently from the most populated areas. However, this result can be explained considering that the hornet shows a preference for nesting in the countryside (e.g. hollow trees) (Matsuura and Yamane 1991).

This pilot study highlights the fact that citizen scientists can be a valuable aid to integrate data on large areas (Lye et al. 2012; Roy et al. 2015). In fact, citizen identification was highly accurate (about 80%), which is considered as an acceptable accuracy percentage in ecological studies (Cohn 2008). Our results are even more encouraging, considering that citizen training was very limited. However, it is important to highlight that the high proportion of correct reports was also due to the absence of other hornet species, which could be misidentified with *V. crabro* by the citizens, in Sardinia. Despite this, participants were more accurate in identifying nests than individuals, as a consequence of misidentification of hornet adults with similar vespid species. Therefore, the most common identification errors observed in the present study will be used to improve the future monitoring protocols by including *Scolia* spp. and *Eumenus* spp. pictures in the next identification guide.

The participation of volunteers from various areas of the island, including those where the hornet was not present, highlighted that the publicity campaign was effective throughout the whole island. Volunteers represent a large free work force and often have more access to private land compared to scientists, which is a major advantage in relation to the early detection of alien species (Lepczyk 2005), but their recruitment is sometimes difficult. Furthermore, volunteers are reluctant to perform routine procedures and observations repeated in time (Delaney et al. 2008), as found in our study, where only two out of 125 participants reported data from trap captures.

This paper also outlined the profile of the citizen willing to participate in the public monitoring of *V. crabro*. Participants were mainly middle-aged males with a medium

education level and working in contact with nature. This result was not influenced by the demographic trend of the Sardinian population, as the number of middle-aged males and females in Sardinia in 2018 was very similar (49.9 % vs 50.1 %) (http://dati.istat.it/Index.aspx?DataSetCode=DCIS_POPRES1#). It was also shown that volunteer success in identifying the European hornet did not depend on the parameters investigated in this study (age, gender, education level and job). Although no significant differences were observed amongst job categories, outdoor workers showed a higher proportion of valid reports, indicating that a better predictor for identification accuracy could be citizen occupation. This suggests that working in contact with nature provides citizens with a direct experience with the European hornet, thus facilitating its correct identification. Finally, despite the small scale of this study, our results suggest that the public monitoring network of *V. crabro* in Sardinia could play a key role in the protection of insular ecosystems and it could also represent a valuable early-detection tool for other alien vespid species, such as *V. velutina*, already present in northern Italy (Demichelis et al. 2014; Lioy et al. 2019).

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References

Baracchi D, Cusseau G, Pradella D, Turillazzi S (2010) Defence reactions of *Apis mellifera ligustica* against attacks from the European hornet *Vespa crabro*. Ethology Ecology & Evolution 22: 281–294. https://doi.org/10.1080/03949370.2010.502323

Beggs JR, Brockerhoff EG, Corley JC, Kenis M, Masciocchi M, Muller F, Rome Q, Villemant C (2011) Ecological effects and management of invasive alien Vespidae. BioControl 56: 505–526. https://doi.org/10.1007/s10526-011-9389-z

Bloniarz DV, Ryan HDP (1996) The use of volunteer initiatives in conducting urban forest resource inventories. Journal of Arboriculture 22: 75–82.

Bourdeau PE, Pangle KL, Peacor SD (2011) The invasive predator *Bythotrephes* induces changes in the vertical distribution of native copepods in Lake Michigan. Biological Invasions 13: 2533–2545. https://doi.org/10.1007/s10530-011-0073-0

Brandon A, Spyreas G, Molano-Flores B, Carroll C, Ellis J (2003) Can volunteers provide reliable data for forest vegetation surveys? Natural Areas Journa 23: 254–262.

Carpenter JM, Kojima J (1997) Checklist of the species in the subfamily Vespinae (Insecta: Hymenoptera: Vespidae). Natural history bulletin of Ibaraki University 1: 51–92.

Choi MB, Martin SJ, Lee JW (2012) Distribution, spread, and impact of the invasive hornet *Vespa velutina* in South Korea. Journal of Asia-Pacific Entomology 15: 473–477. https://doi.org/10.1016/j.aspen.2011.11.004

Cini A, Cappa F, Petrocelli I, Pepiciello I, Bortolotti L, Cervo R (2018) Competition between the native and the introduced hornets *Vespa crabro* and *Vespa velutina*: a comparison of potentially relevant life-history traits. Ecological Entomology 43: 351–362. https://doi.org/10.1111/een.12507

Cohn JP (2008) Citizen science: can volunteers do real research? BioScience 58: 192–197. https://doi.org/10.1641/B580303

Costa A (1883) Notizie ed osservazioni sulla Geo-Fauna sarda Memoria Seconda. Risultamento di ricerche fatte in Sardegna nella primavera del 1882. (Results of research conducted in Sardinia during spring in 1882 [in Italian] Atti della Reale Accademia delle Scienze Fisiche e Matematiche 1(2): 1–109.

Crall AW, Newman GJ, Jarnevich CS, Stohlgren TJ, Waller DM, Graham J (2010) Improving and integrating data on invasive species collected by citizen scientists. Biological Invasions 12: 3419–3428. https://doi.org/10.1007/s10530-010-9740-9

Crall AW, Newman GJ, Stohlgren TJ, Holfelder KA, Graham J, Waller DM (2011) Assessing citizen science data quality: an invasive species case study. Conservation Letters 4: 433–442. https://doi.org/10.1111/j.1755-263X.2011.00196.x

Delaney DG, Sperling CD, Adams CS, Leung B (2008) Marine invasive species: validation of citizen science and implications for national monitoring networks. Biological Invasions 10: 117–128. https://doi.org/10.1007/s10530-007-9114-0

Demichelis S, Manino A, Minuto G, Mariotti M, Porporato M (2014) Social wasp trapping in north west Italy: comparison of different bait-traps and first detection of *Vespa velutina*. Bulletin of Insectology 67: 307–317.

Dubatolov V, Kojima J, Carpenter JM, Lvovsky A (2003) Subspecies of *Vespa crabro* in two different papers by Birula in 1925. Entomological Science 6: 215–216. https://doi.org/10.1046/j.1343-8786.2003.00037.x

Ericsson G, Wallin K (1999) Hunter observations as an index of moose *Alces alces* population parameters. Wildlife Biology 5: 177–185. https://doi.org/10.2981/wlb.1999.022

Fernández J (2004) Distribution of vespid species in Europe. Current Opinion in Allergy and Clinical Immunology 4: 319–324. https://doi.org/10.1097/01.all.0000136760.43571.f2

Gardiner MM, Allee LL, Brown PMJ, Losey JE, Roy HE, Smyth RR (2012) Lessons from lady beetles: accuracy of monitoring data from US and UK citizen-science programs. Frontiers in Ecology and the Environment 10: 471–476. https://doi.org/10.1890/110185

Genet KS, Sargent LG (2003) Evaluation of methods and data quality from a volunteer-based amphibian call survey. Wildlife Society Bulletin 31: 703–714.

Guiglia D (1948) Le Vespe d'Italia. Memorie della Società Entomologica Italiana 27(Suppl.): 5–84.

Guiglia D (1972) Le guêpes sociales (Hymenoptera: Vespidae) d'Europe occidentale et septentrionale. Faune de l'Europe et du Bassin Méditerranéen, 6. Masson et Cie, Paris.

Hulme PE (2009) Trade, transport and trouble: managing invasive species pathways in an era of globalization. Journal of Applied Ecology 46: 10–18. https://doi.org/10.1111/j.1365-2664.2008.01600.x

Landolt PJ, Sierra JM, Unruh TR, Zack RS (2010) A new species of *Vespula*, and first record of *Vespa crabro* L. (Hymenoptera: Vespidae) from Guatemala, Central America. Zootaxa 2629: 61–68. https://doi.org/10.11646/zootaxa.2629.1.4

Lepczyk CA (2005) Integrating published data and citizen science to describe bird diversity across a landscape. Journal of Applied Ecology 42: 672–677. https://doi.org/10.1111/j.1365-2664.2005.01059.x

Lester PJ, Beggs JR (2019) Invasion success and management strategies for social *Vespula* wasps. Annual Review of Entomology 64: 51–71. https://doi.org/10.1146/annurev-ento-011118-111812

Lioy S, Manino A, Porporato M, Laurino D, Romano A, Capello M, Bertolino S (2019) Establishing surveillance areas for tackling the invasion of *Vespa velutina* in outbreaks and over the border of its expanding range. NeoBiota 46: 51–69 https://doi.org/10.3897/neobiota.46.33099

Lodge DM, Williams S, MacIsaac HJ, Hayes KR, Leung B, Reichard S, Mack RN, Moyle PB, Smith M, Andow DA, Carlton JT, McMichael A (2006) Biological invasions: recommendations for U.S. policy and management. Ecological Applications 16: 2035–2054. https://doi.org/10.1890/1051-0761(2006)016[2035:BIRFUP]2.0.CO;2

Lye GC, Osborne JL, Park KJ, Goulson D (2012) Using citizen science to monitor *Bombus* populations in the UK: nesting ecology and relative abundance in the urban environment. Journal of Insect Conservation 16: 697–707. https://doi.org/10.1007/s10841-011-9450-3

Mack RN, Simberloff D, Lonsdale WM, Evans H, Clout M, Bazzaz FA (2000) Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications 10: 689–710. https://doi.org/10.1890/1051-0761(2000)010[0689:BICEGC]2.0.CO;2

Mason F, Roversi PF, Audisio P, Bologna MA, Carpaneto GM, Antonini G, Mancini E, Sabbatini Peverieri G, Mosconi F, Solano E, Maurizi E, Maura M, Chiari S, Sabatelli S, Bardiani M, Toni I, Redolfi De Zan L, Rossi De Gasperis S, Tini M, Cini A, Zauli A, Nigro G, Bottacci A, Hardersen S, Campanaro A (2015) Monitoring of insects with public participation (MIPP; EU LIFE project 11 NAT/IT/000252): overview on a citizen science initiative and a monitoring programme (Insecta: Coleoptera; Lepidoptera; Orthoptera). Fragmenta Entomologica 47: 51–52. https://doi.org/10.4081/fe.2015.134

Matsuura M, Yamane S (1990) Biology of the Vespine Wasps. Springer Verlag, Berlin. https://doi.org/10.1007/978-3-642-75230-8

Matsuura M, Yamane S (1991) Vespa and Provespa. In: Ross KG, Matthews RW (Eds) The Social Biology of Wasps. Cornell University Press, Ithaca, 232–262. https://doi.org/10.7591/9781501718670-010

Monceau K, Moreau J, Poidatz J, Bonnard O, Thiéry D (2015a) Behavioral syndrome in a native and an invasive hymenoptera species. Insect Science 22: 541–548. https://doi.org/10.1111/1744-7917.12140

Monceau K, Maher N, Bonnard O, Thiéry D (2015b) Evaluation of competition between a native and an invasive hornet species: do s https://doi.org/10.1017/S0007485315000280 easonal phenologies overlap? Bulletin of Entomological Research 105: 462–469.

Morse RA, Nowogrodzki R (1990) Honey Bee Pests Predators and Diseases (2nd edn). Cornell University Press, Ithaca.

Mumby PJ, Harborne AR, Raines PS, Ridley JM (1995) A critical assessment of data derived from Coral Cay Conservation volunteers. Bulletin of Marine Science 56: 737–751.

Pimentel D, Zuniga R, Morrison D (2005) Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics 52: 273–288. https://doi.org/10.1016/j.ecolecon.2004.10.002

Pusceddu M, Floris I, Buffa F, Salaris E, Satta A (2017) Agonistic interactions between the honeybee (*Apis mellifera ligustica*) and the European wasp (*Vespula germanica*) reveal context-dependent defense strategies. PLoS ONE 12(7): e0180278. https://doi.org/10.1371/journal.pone.0180278

Pusceddu M, Mura A, Floris I, Satta A (2018) Feeding strategies and intraspecific competition in German yellowjacket (*Vespula germanica*). PLoS ONE 13(10): e0206301. https://doi.org/10.1371/journal.pone.0206301

R Core Team (2018) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. http://www.R-project.org

Ratnieks FL, Schrell F, Sheppard RC, Brown E, Bristow OE, Garbuzov M (2016) Data reliability in citizen science: learning curve and the effects of training method, volunteer background and experience on identification accuracy of insects visiting ivy flowers. Methods in Ecology and Evolution 7:1226–1235. https://doi.org/10.1111/2041-210X.12581

Roy HE, Baxter E, Saunders A, Pocock MJ (2016) Focal plant observations as a standardised method for pollinator monitoring: Opportunities and limitations for mass participation citizen science. PloS ONE 11(3): e0150794. https://doi.org/10.1371/journal.pone.0150794

Roy HE, Rorke SL, Beckmann B, Booy O, Botham MS, Brown PM, Harrower C, Noble D, Sewell J, Walker K (2015) The contribution of volunteer recorders to our understanding of biological invasions. Biological Journal of the Linnean Society 115: 678–689. https://doi.org/10.1111/bij.12518

Schmeller DS, Henry PY, Julliard R, Gruber B, Clobert J, Dziock F, Lengyel S, Nowicki P, Déri E, Budrys E, Kull T, Tali K, Bauch B, Settele J, Van Swaay C, Kobler A, Babij V, Papastergiadou E, Henle K (2009) Advantages of volunteer-based biodiversity monitoring in Europe. Conservation Biology 23: 307–316. https://doi.org/10.1111/j.1523-1739.2008.01125.x

Shaw FR, Weidhaas Jr J (1956) Distribution and habits of the giant hornet in North America. Journal of Economic Entomology 49: 275 pp. https://doi.org/10.1093/jee/49.2.275

Snyder WE, Evans EW (2006) Ecological effects of invasive arthropod generalist predators. Annual Review of Ecology, Evolution, and Systematics 37: 95–122. https://doi.org/10.1146/annurev.ecolsys.37.091305.110107

Sokal RR, Rohlf FJ (1981) Biometry (2nd edn). WH Freeman and Co., New York.

Spradbery JP, Maywald GF (1992) The distribution of the European or German wasp, *Vespula germanica* (F.) (Hymenoptera: Vespidae), in Australia: past, present and future. Australian Journal of Zoology 40: 495–510. https://doi.org/10.1071/ZO9920495

Stoch F (2003) Checklist of the species of the Italian fauna. http://www.faunaitalia.it/checklist/ [Accessed 7 February 2019]

Stohlgren TJ, Schnase JL (2006) Risk analysis for biological hazards: what we need to know about invasive species. Risk Analysis 26: 163–173. https://doi.org/10.1111/j.1539-6924.2006.00707.x